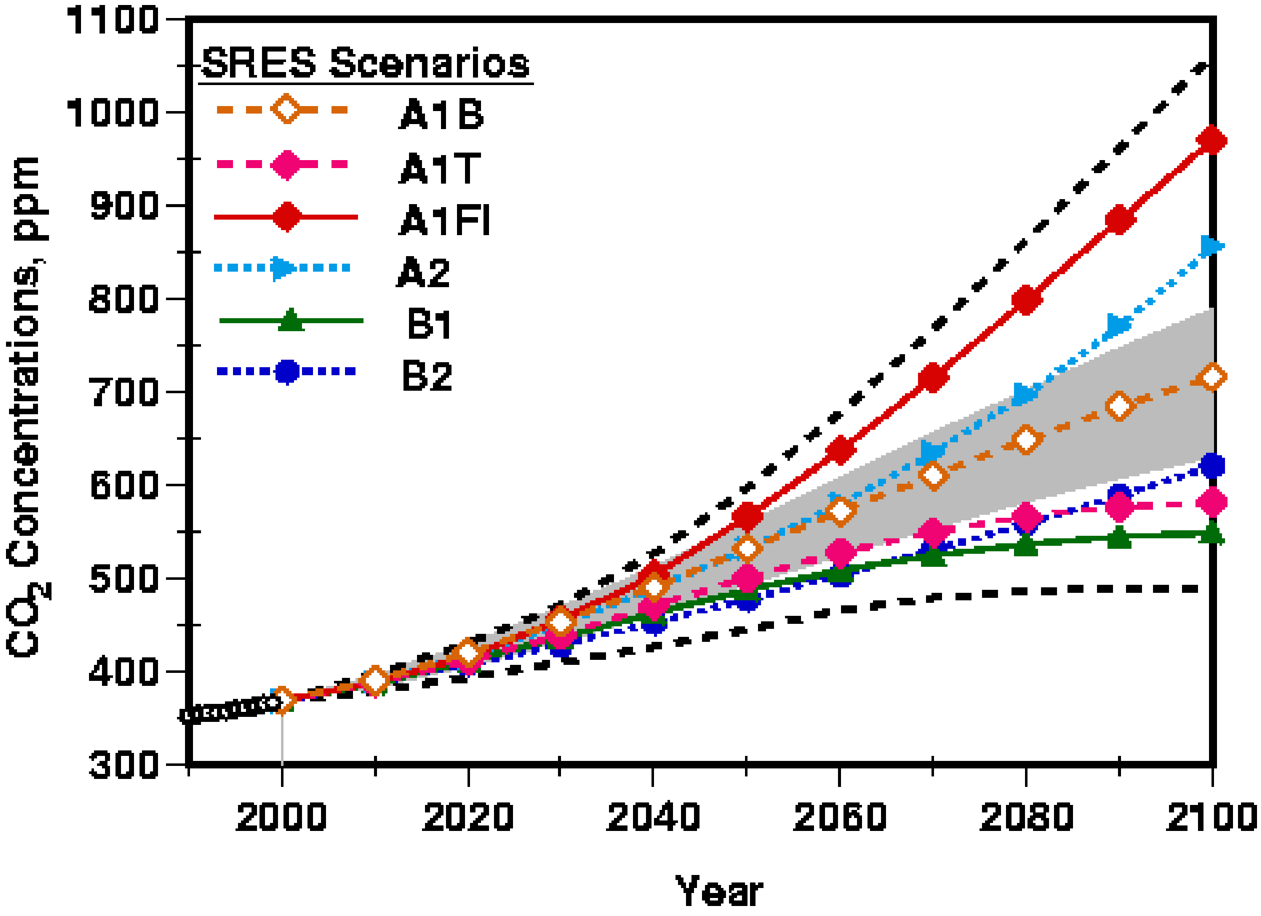
The Response of Photosynthesis to 10 years of ***F***ree ***A***ir ***C***O_2 ***E***nrichment (FACE) in ***Lolium perenne***

Lisa Ainsworth
Department of Crop Sciences
University of Illinois, Urbana-Champaign

Photosynthesis and ***A***tmospheric
Change ***Lab***oratory

Rising [CO_2] and Grasslands



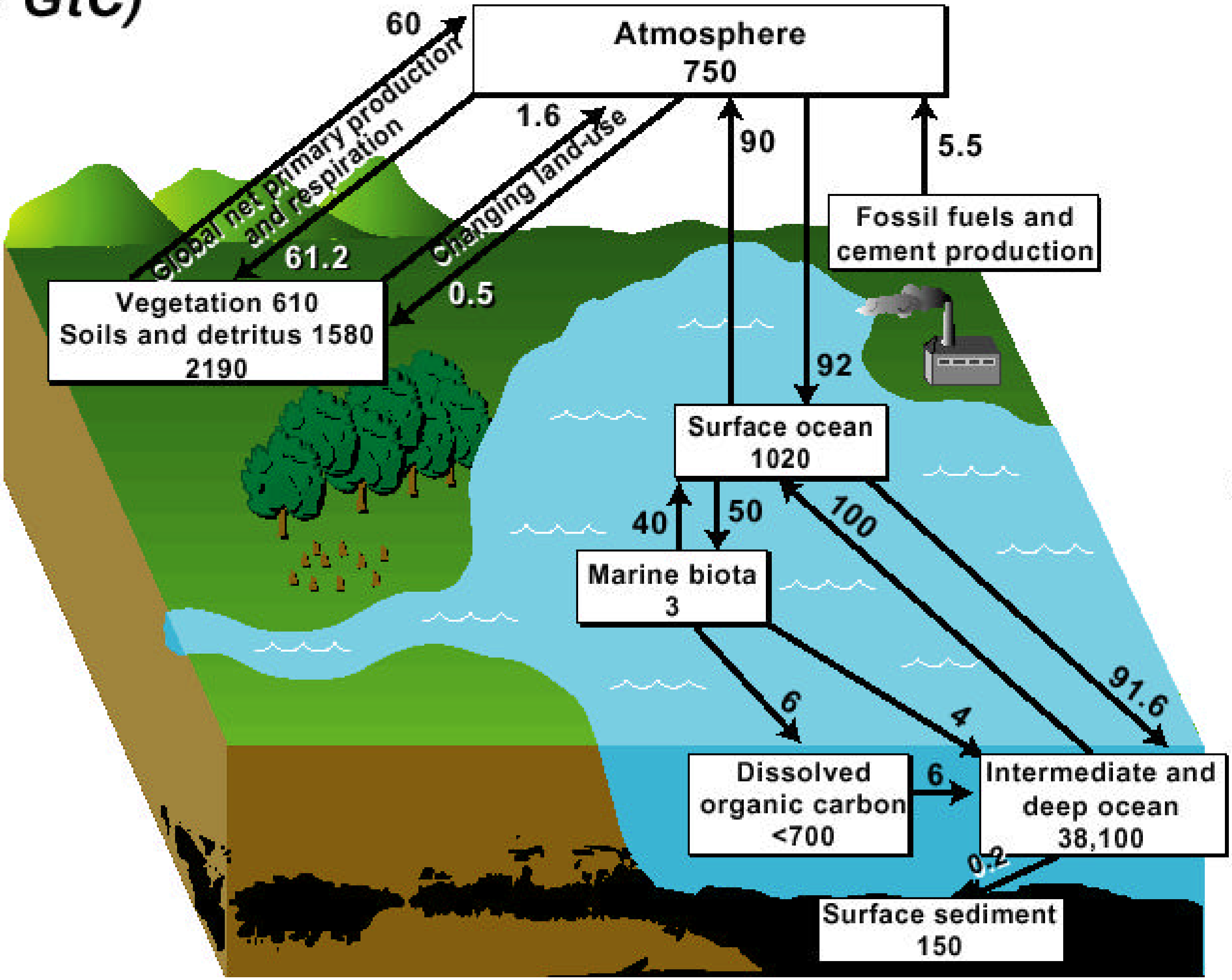
- Atmospheric [CO_2] is rising at ~ 1.5 ppm per year.

- Grasslands cover ~ 20% of the world's land surface and contain >10% of global C stocks.

- The role of grasslands is important in the global C budget because of their high capacity to sequester C.

Houghton *et al*. 2001 *Climate Change 2001.*

Global Carbon Cycle
(in GtC)



Photosynthesis: The Key Physiological Process

http://www.fao.org/ag/AGP/AGPC/doc/Gallery/pictures/trirep.htm

- Photosynthesis is a key process by which plants sense and respond to rising [CO_2].

Effects of Elevated [CO_2] on C_3 Plants

Leaf level responses

- 30 – 40% increase in photosynthesis (*A*)
- 20 – 25% decrease in stomatal conductance (g_s)
- 14% decrease in *A* measured at ambient [CO_2] (360 ppm)
- 15% decrease in Rubisco concentration
- 20% decrease in leaf N
- 40% increase in leaf [CH_2O]

Drake *et al*. 1997 *Ann Rev Plant Phys & Plant Mol Biol*, **48**, 607-637.

Whole plant level responses

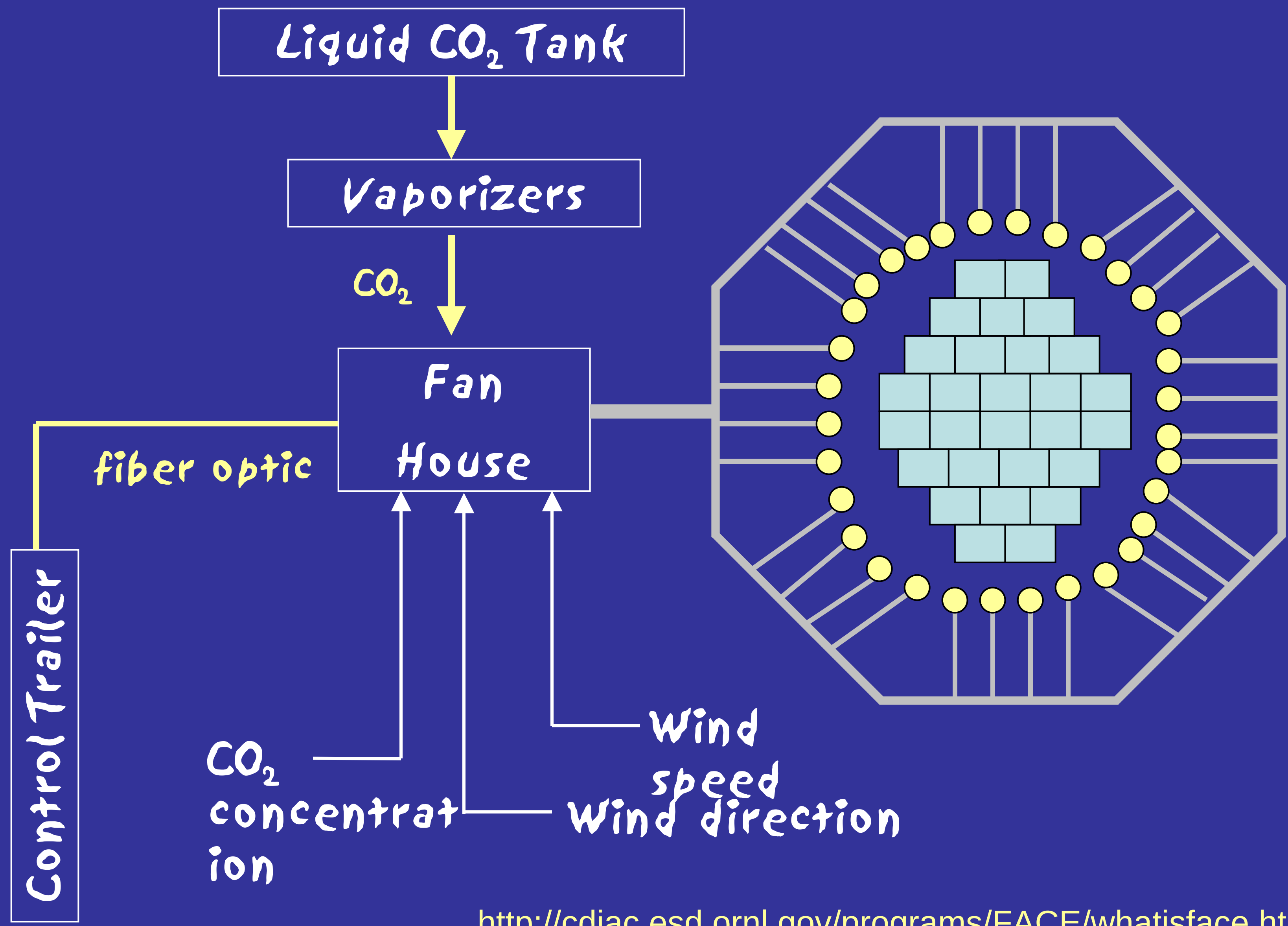
- 40% increase in shoot biomass
- 40% increase in root biomass
- 15% increase in leaf area
- 15% increase in tiller number
- 44% increase in total plant biomass

Wand *et al*. 1999 *Global Change Biol*, **5**, 723-741.

Swiss (ETH) FACE Experiment

http://www.fb.ipw.agrl.ethz.ch/FACE.html

FACE: ***F***ree ***A***ir gas ***C***oncentration ***E***nrichment



http://cdiac.esd.ornl.gov/programs/FACE/whatisface.html


www.soyface.uiuc.edu

Experimental Design

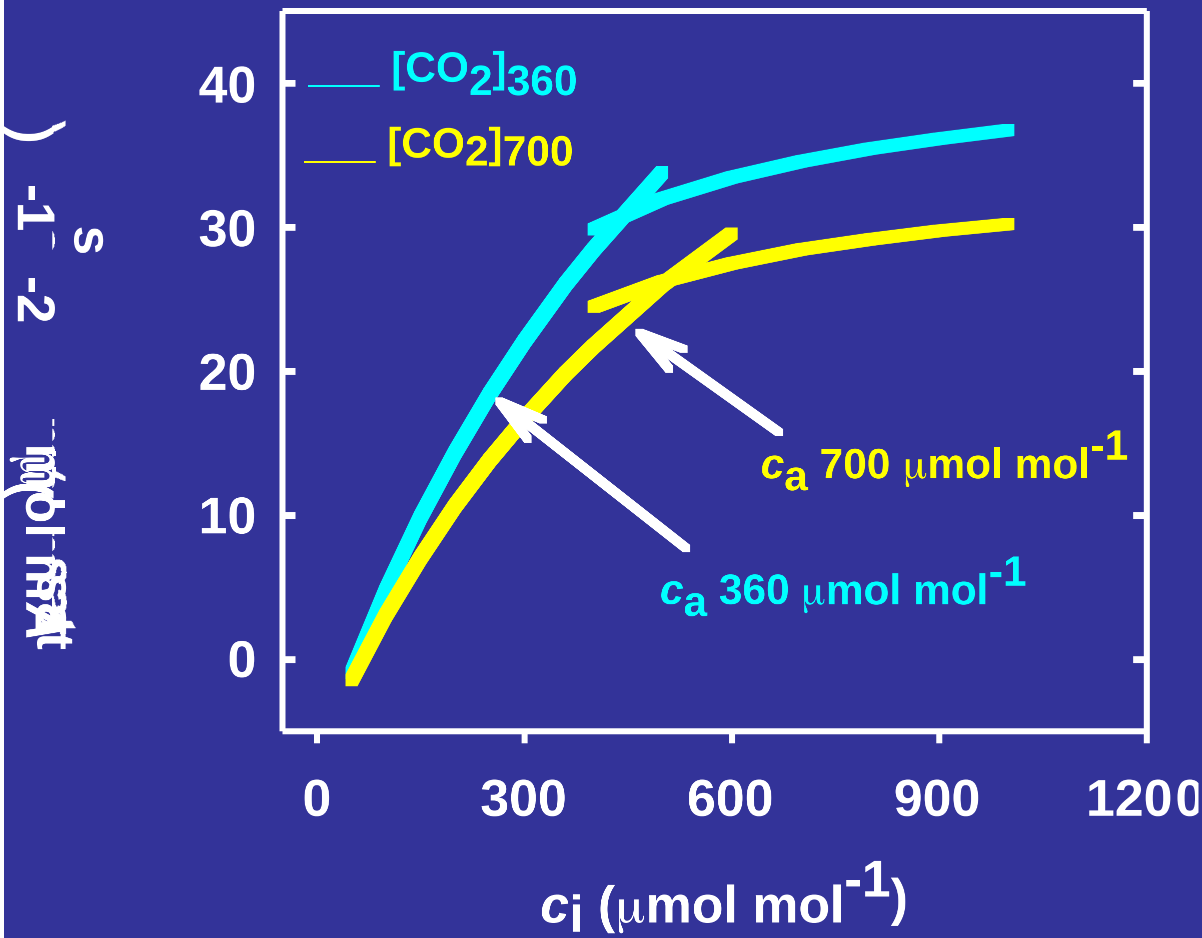
Primary Objective

- Characterize the photosynthetic response of *Lolium perenne* to elevated [CO_2].

Hypotheses and Predictions

- Photosynthetic acclimation does not inevitably reduce carbon uptake at elevated [CO_2].
- Acclimation of photosynthesis will be more pronounced under N limiting conditions.
- If increased acclimation of photosynthesis to elevated [CO_2] under low N results because sink development is limited by N supply, then in *L. perenne*, cutting should alleviate acclimation.

Acclimation of Photosynthesis to Elevated $[CO_2]$

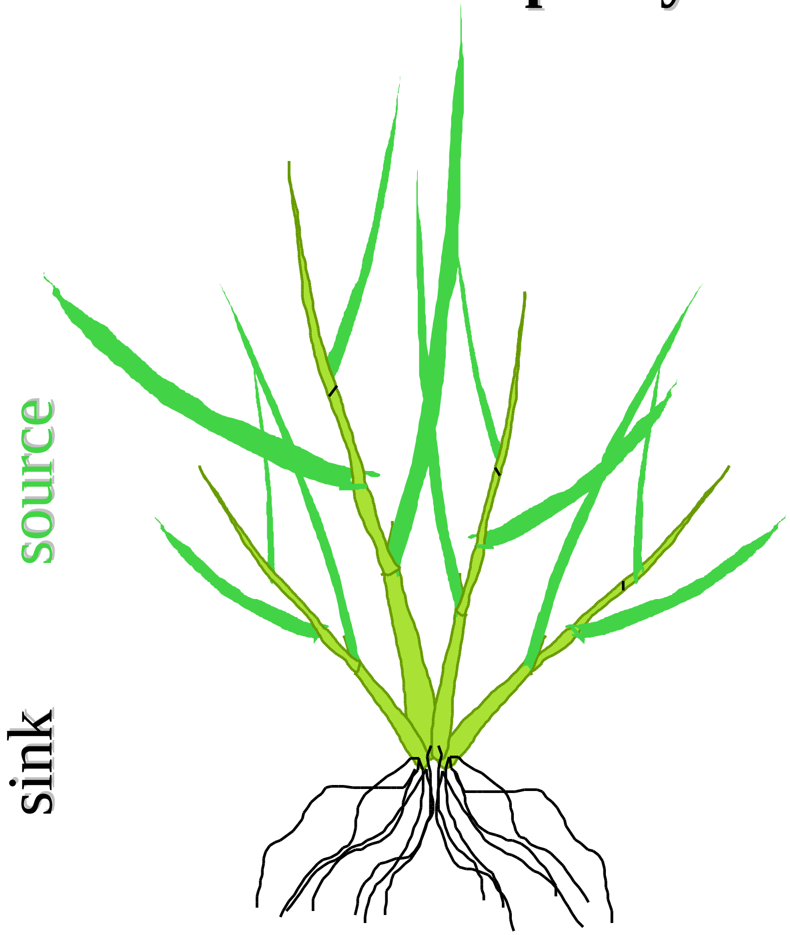


- In elevated $[CO_2]$ A_{growth} increases 43%, but A_{360} decreases 14%. (Drake *et al*. 1997. Ann. Rev. Plant Phys. Mol. Bio. 48: 609.)

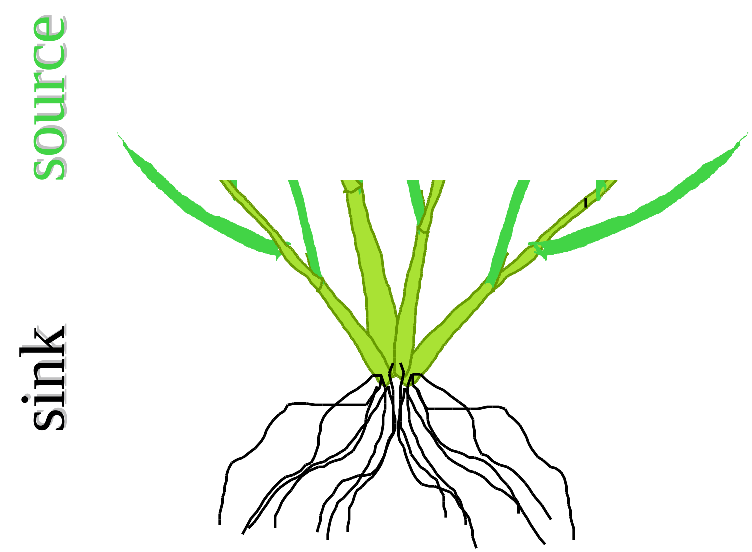
- Decrease in photosynthetic capacity is ***acclimation***.

Lolium perenne in intensive cutting regime

Before cut, high source/sink capacity



After cut, low source/sink capacity



Primary Objective

• Characterize the photosynthetic responses of ***Lolium perenne*** to elevated [CO_2].

- Take photosynthetic measurements at the Swiss FACE site: Fall 2000, Spring 2001 and 2002.

- Assimilate and review all of the photosynthetic data from the past 10 years of the experiment.

L. perenne Diurnal Photosynthetic Measurements

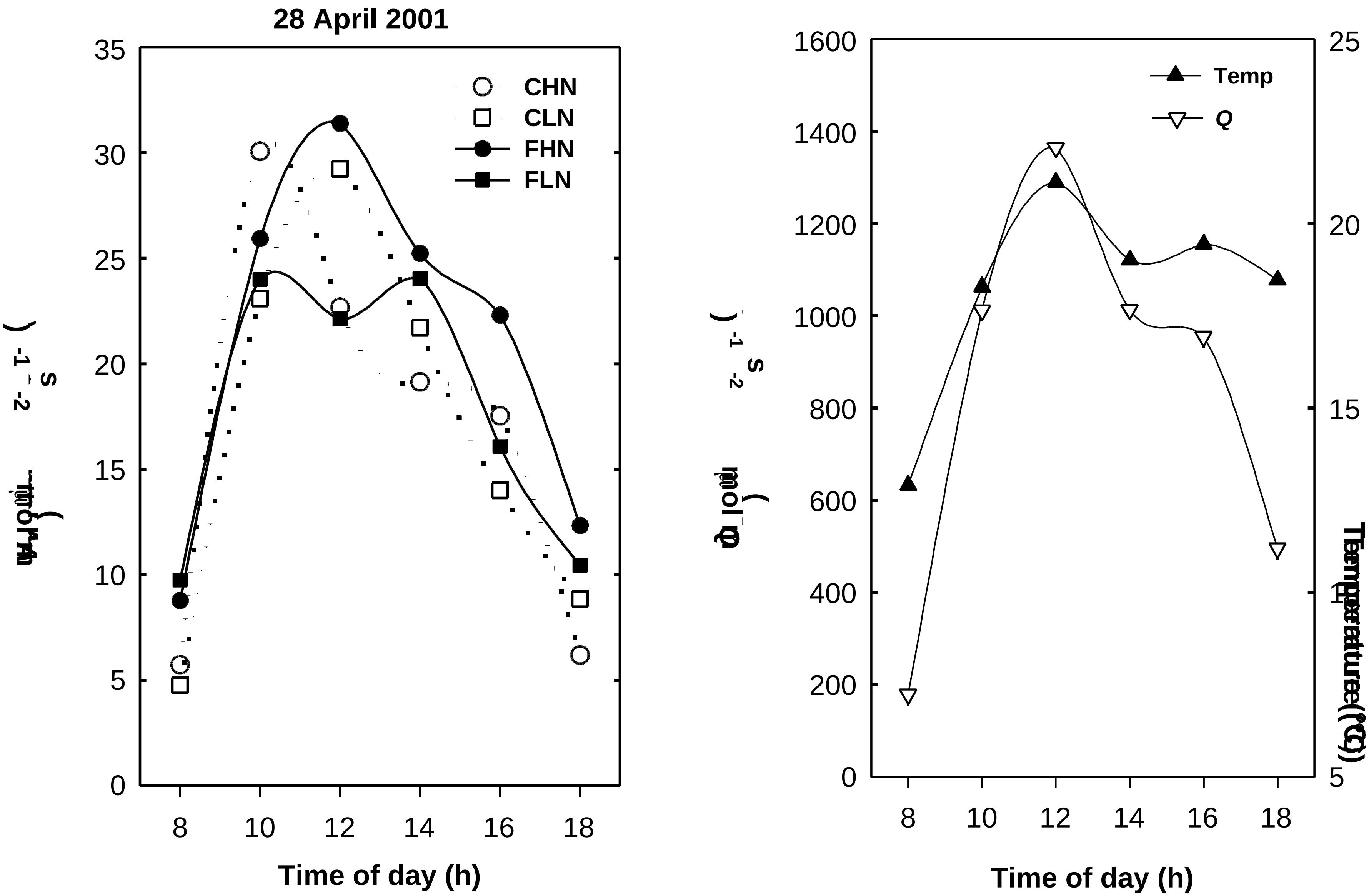
• Photosynthesis was measured from dawn to dusk at approximately 2 to 3 hour intervals.

• Measurements were taken at the growth [CO_2], and at the temperature, *VPD*, and *Q* incident at that point in time.

• Measurements were taken with portable, infra-red gas analysis systems (CIRAS 1, PP Systems, Hitchin, UK or LI-6400, LICOR, Lincoln, NE).

• Measurements were taken on intact vegetation, on the mid-section of the youngest, fully expanded laminae.

Photosynthesis *in situ*

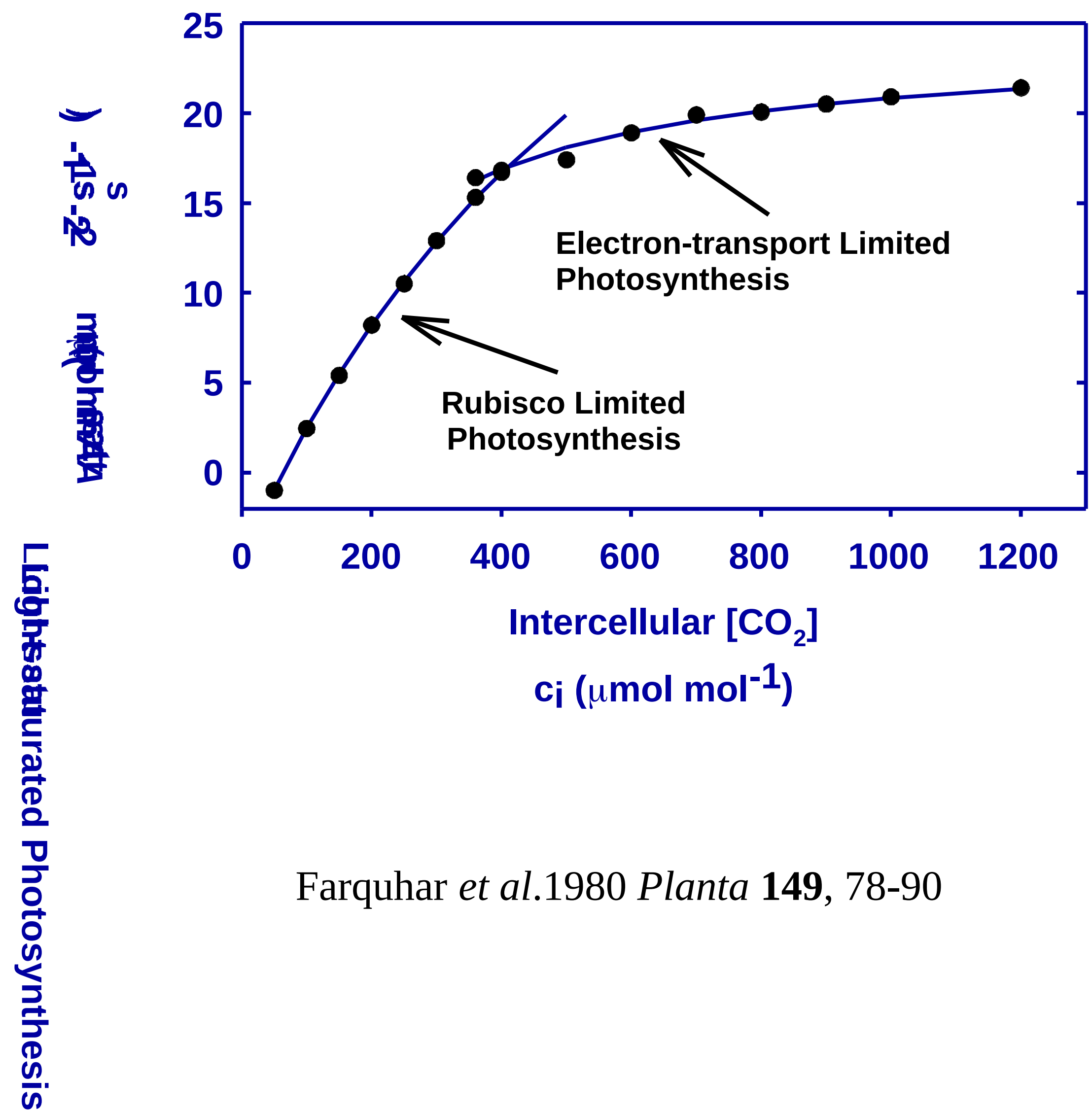


CLN: Control, Low N FLN: FACE, Low N CHN: Control, High N FHN: FACE, High N

A / c_i Response Measurements

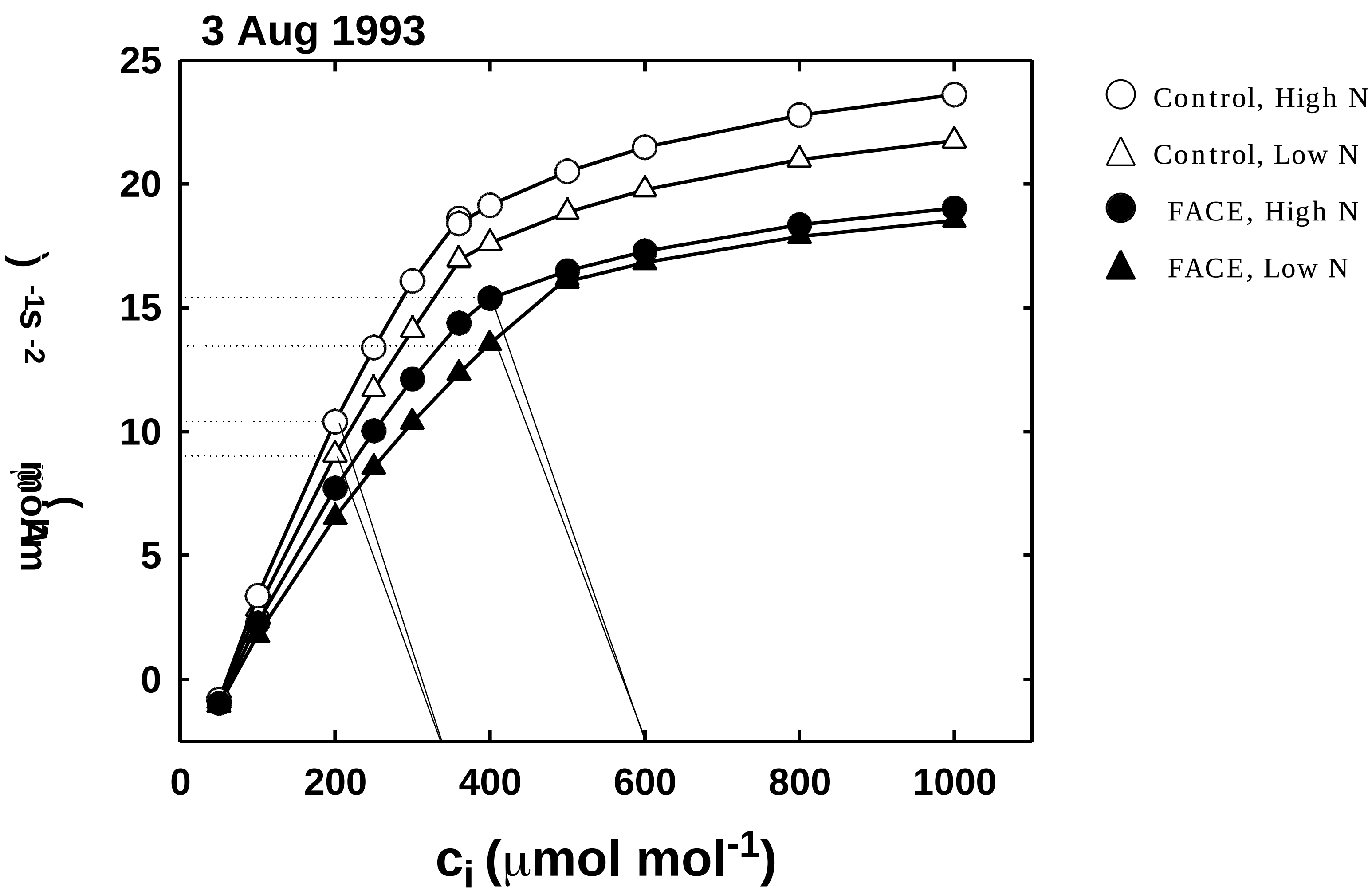
• Leaf CO_2 assimilation rate (A) was determined in response to changes in intercellular CO_2 concentration (c_i) with a portable, steady-state gas-exchange system.

• Photosynthetic parameters $V_{c,max}$ (maximum carboxylation velocity of Rubisco) and J_{max} (maximum electron transport) were fit using the Farquhar *et al*. (1980) photosynthesis model.



Farquhar *et al*.1980 *Planta* **149**, 78-90

A/c_i Response Measurements



Meta-Analysis

• The daily integral of carbon fixation (***A'***); stomatal conductance (g_s) measured at midday in the field; light-saturated net CO_2 assimilation rate (A_{sat}); maximum RuBP-saturated rate of carboxylation ($V_{c,max}$); and light-saturated potential rate of electron transport (J_{max}) were quantitatively reviewed.

• The response ratio (r = Xe/Xa) was used as the metric, and means were weighted according to the statistical precision of the individual experiment (Curtis and Wang, 1998).

• Categorical Variables and Levels

Year: 1993-1995; 1996-1997; 2000-2001

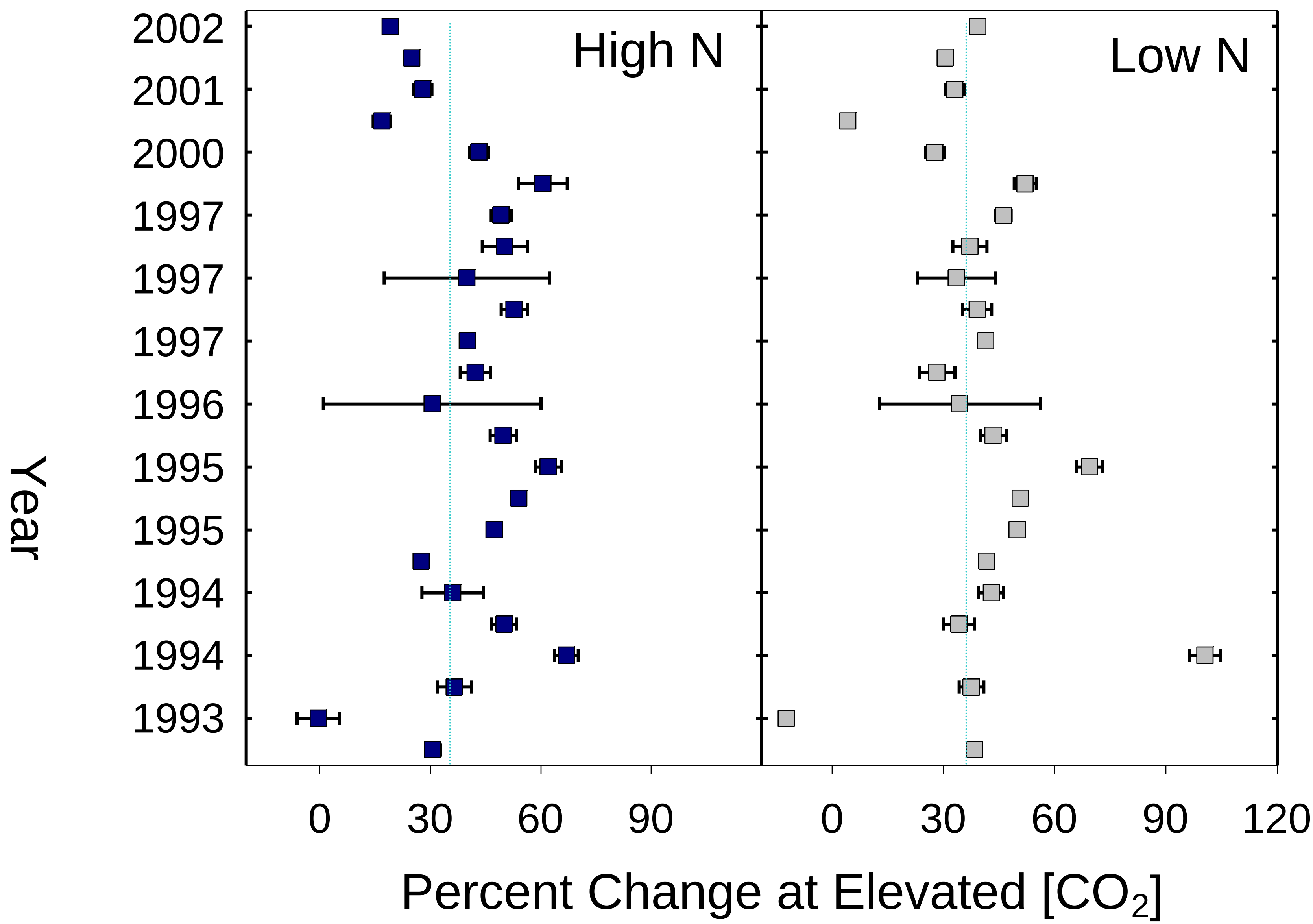
Month: March-May; June-Aug; Sep-Nov

N: High; Low

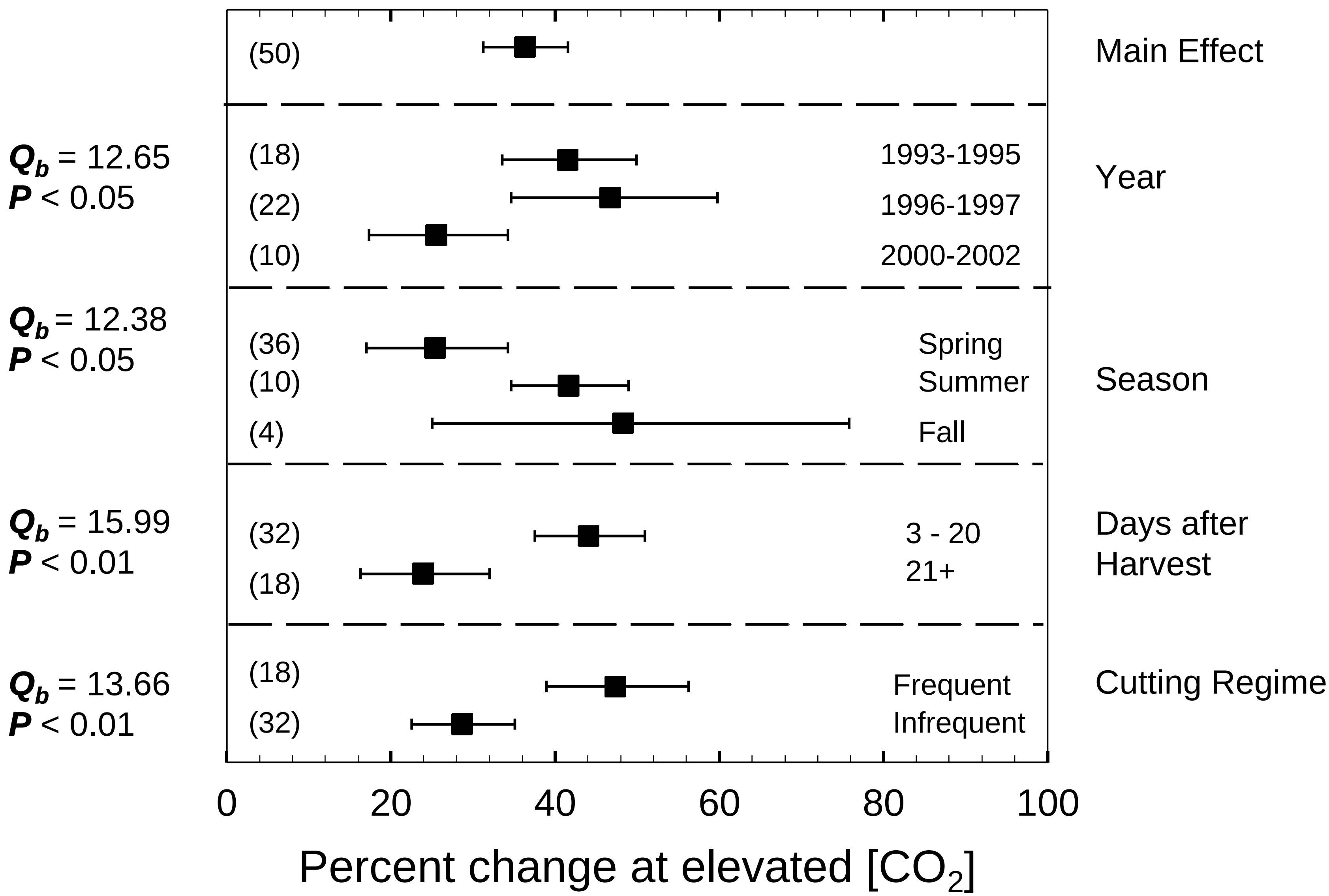
Cutting Regime: 4, 5, 6, 8

Days After Cut: 1-20; 21+

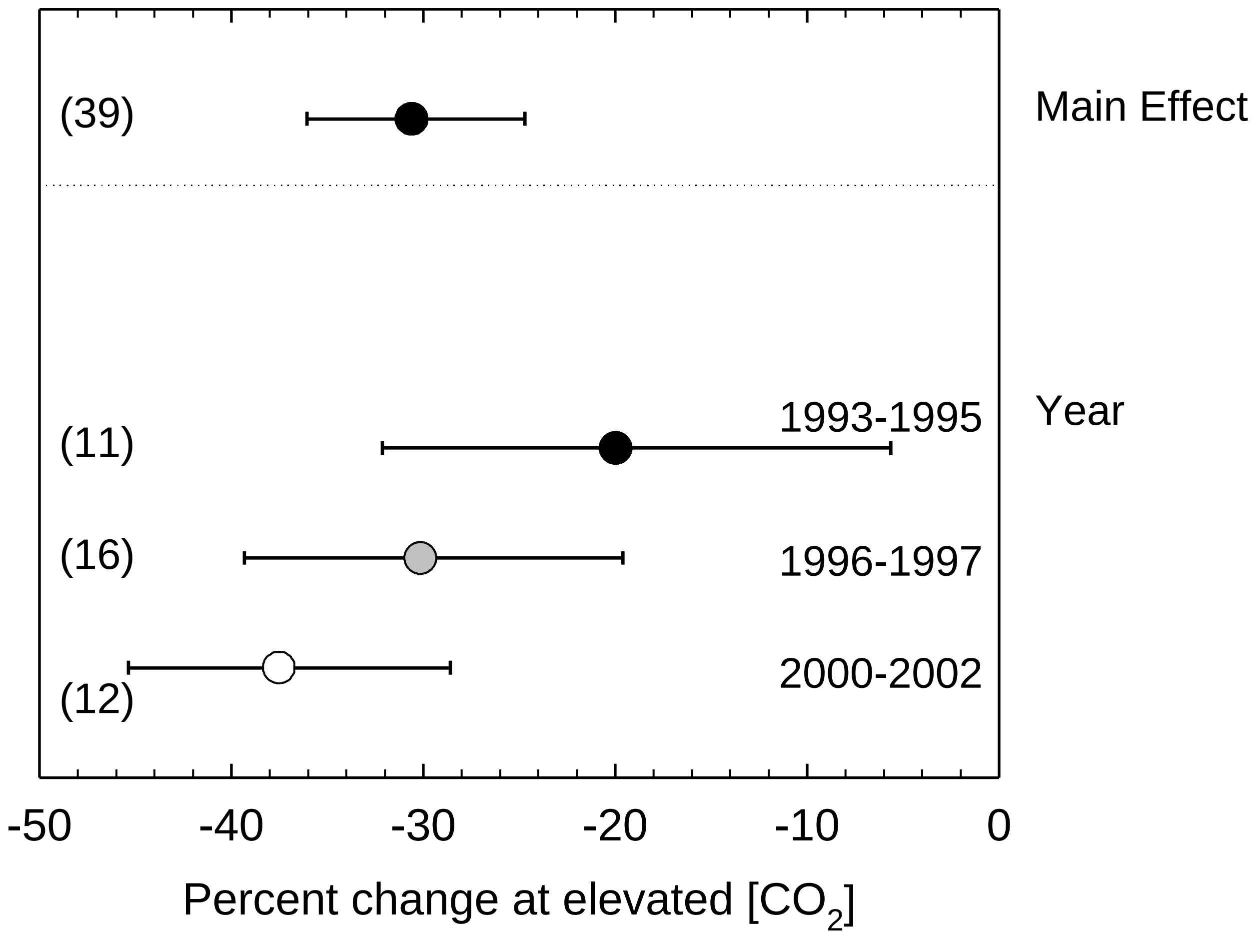
Daily Integrated Carbon Fixation



Daily Integrated Carbon Fixation (*A*')



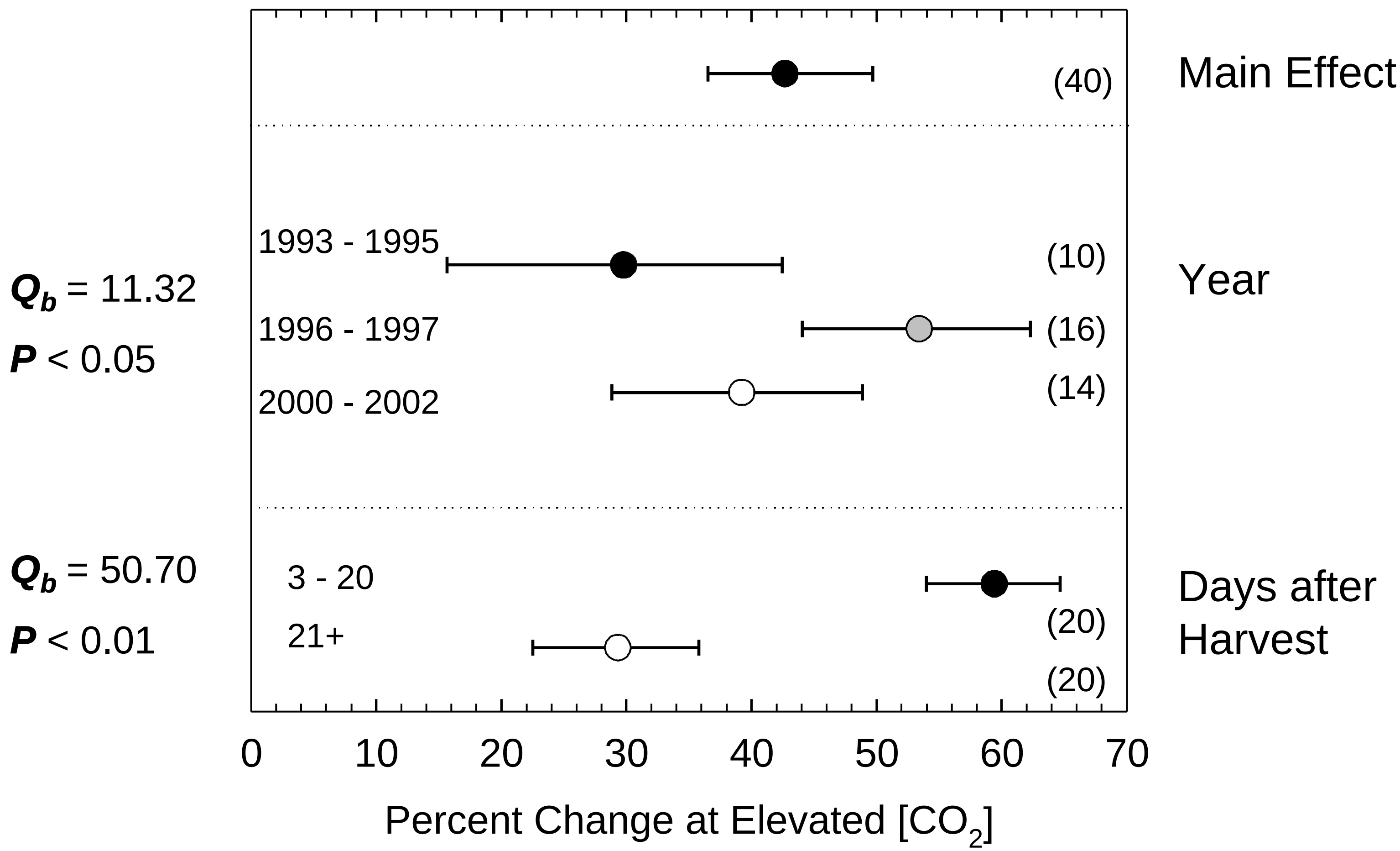
Stomatal Conductance (g_s)



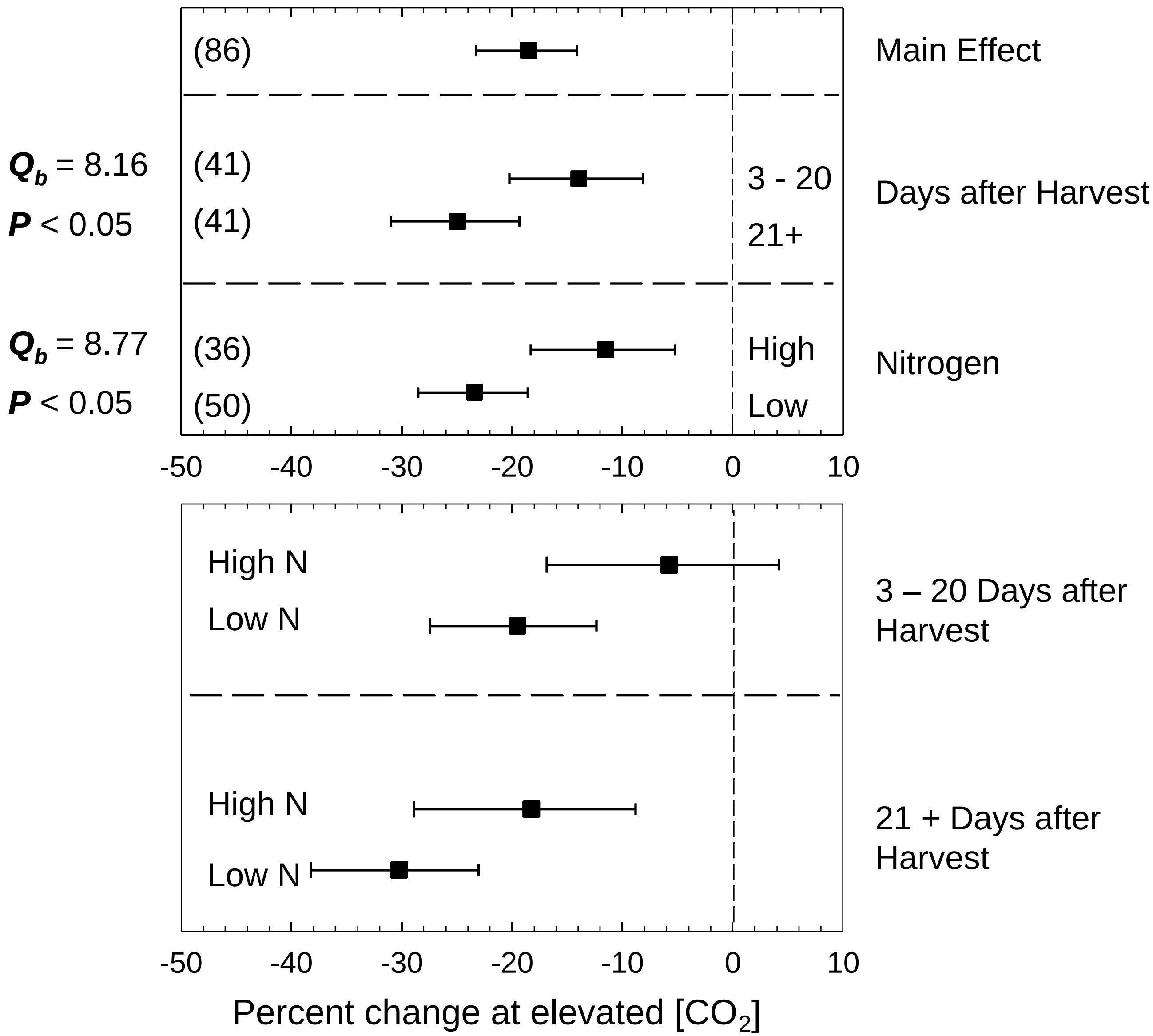
$Q_b = 6.71$

$P < 0.05$

Light Saturated Photosynthetic Rate (A_{sat})



Maximum Rubisco Carboxylation Rate ($V_{c,max}$)



Results Summary

Overall Effects of Growth at Elevated [CO_2]:

- 36% stimulation in daily integrated carbon assimilation ($\boldsymbol{A}'$)
- 31% reduction in stomatal conductance
- 43% stimulation in light saturated CO_2 uptake ($\boldsymbol{A}_{sat}$)
- 18% reduction in maximum carboxylation rate ($\boldsymbol{V}_{c,max}$)
- 9% reduction in maximum electron transport ($\boldsymbol{J}_{max}$)

Results Summary

Low N Fertilization Treatment:

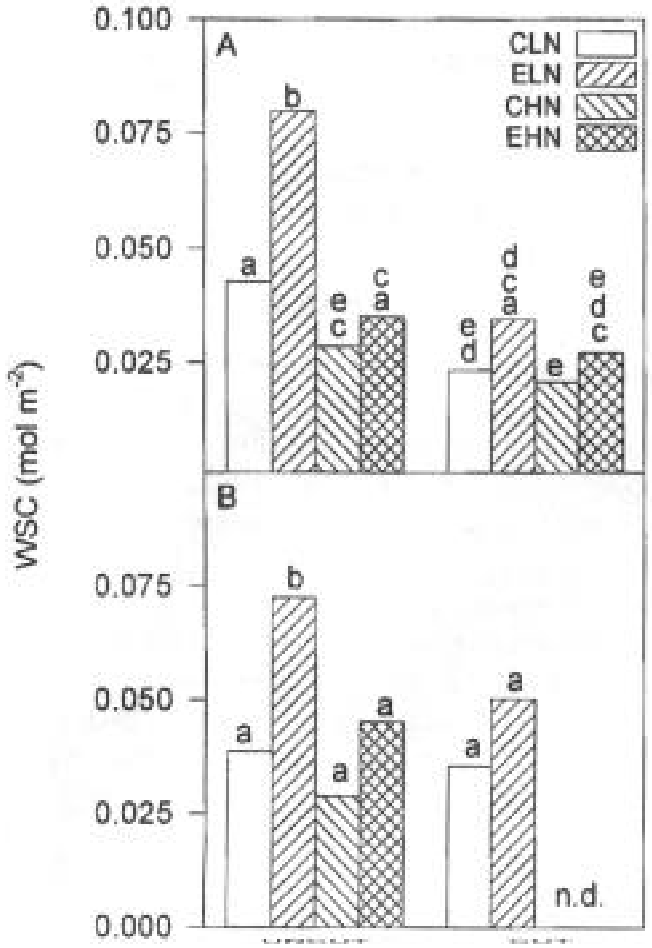
• More pronounced acclimation of photosynthesis (significantly greater reduction in $\boldsymbol{V}_{c,max}$)

Interaction of Days After Cut:

• Decreased stimulation in net C assimilation under Low N conditions

• Greater reduction in $\boldsymbol{V}_{c,max}$ with increasing time after a cut

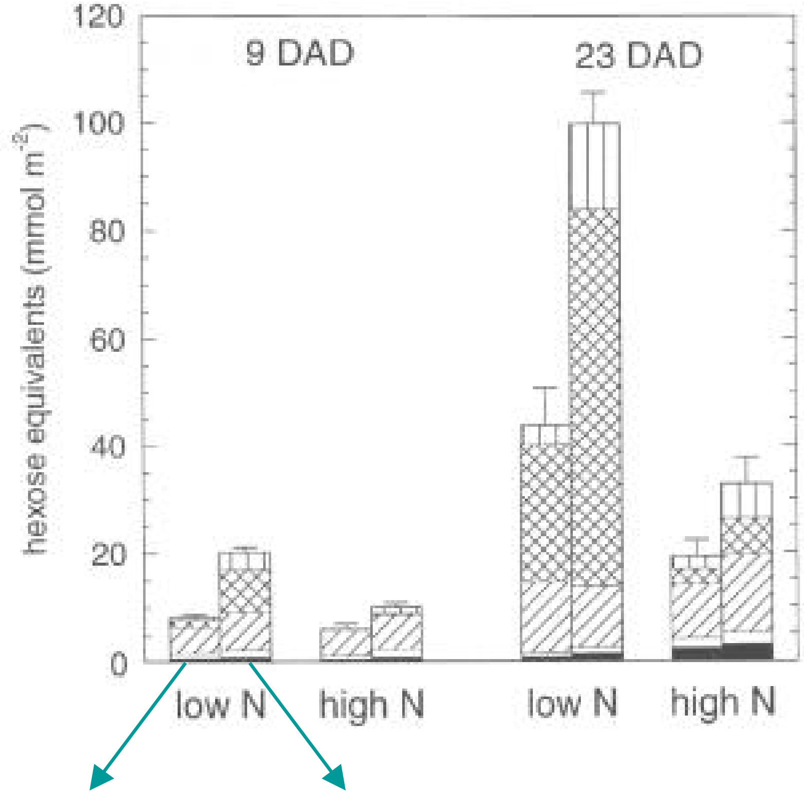
Carbon Sink Limitation



A. Summer 1994; B. Summer 1995

C: Control; E: Elevated

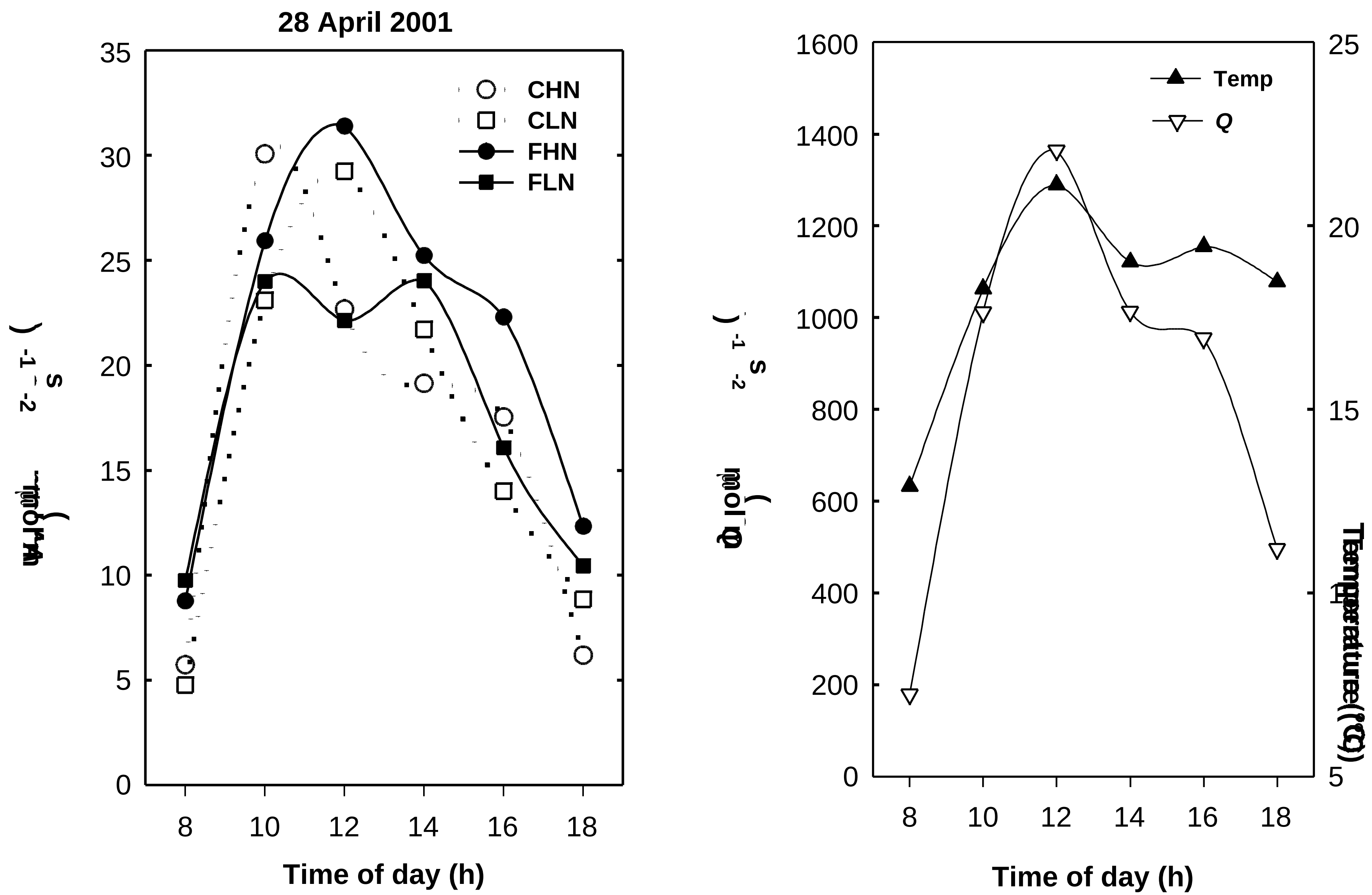
Rogers *et al*. 1998 *Plant Physiol*, **118**, 683-689



9 DAD: 25 June 1997
23 DAD: 9 July 1997

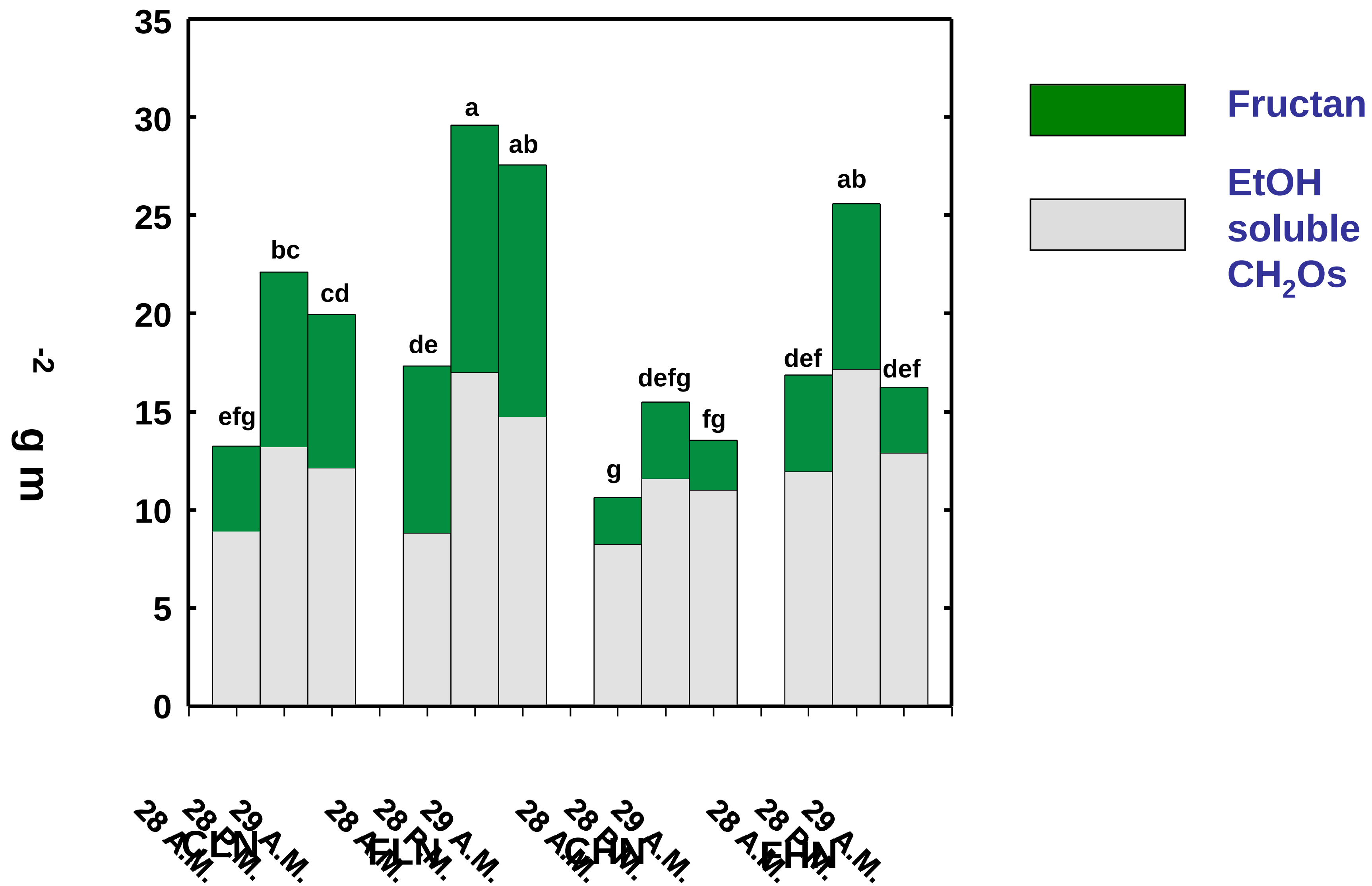
Isopp *et al*. 2000 *Plant, Cell & Environ*, **23**, 597-607

Photosynthesis *in situ*

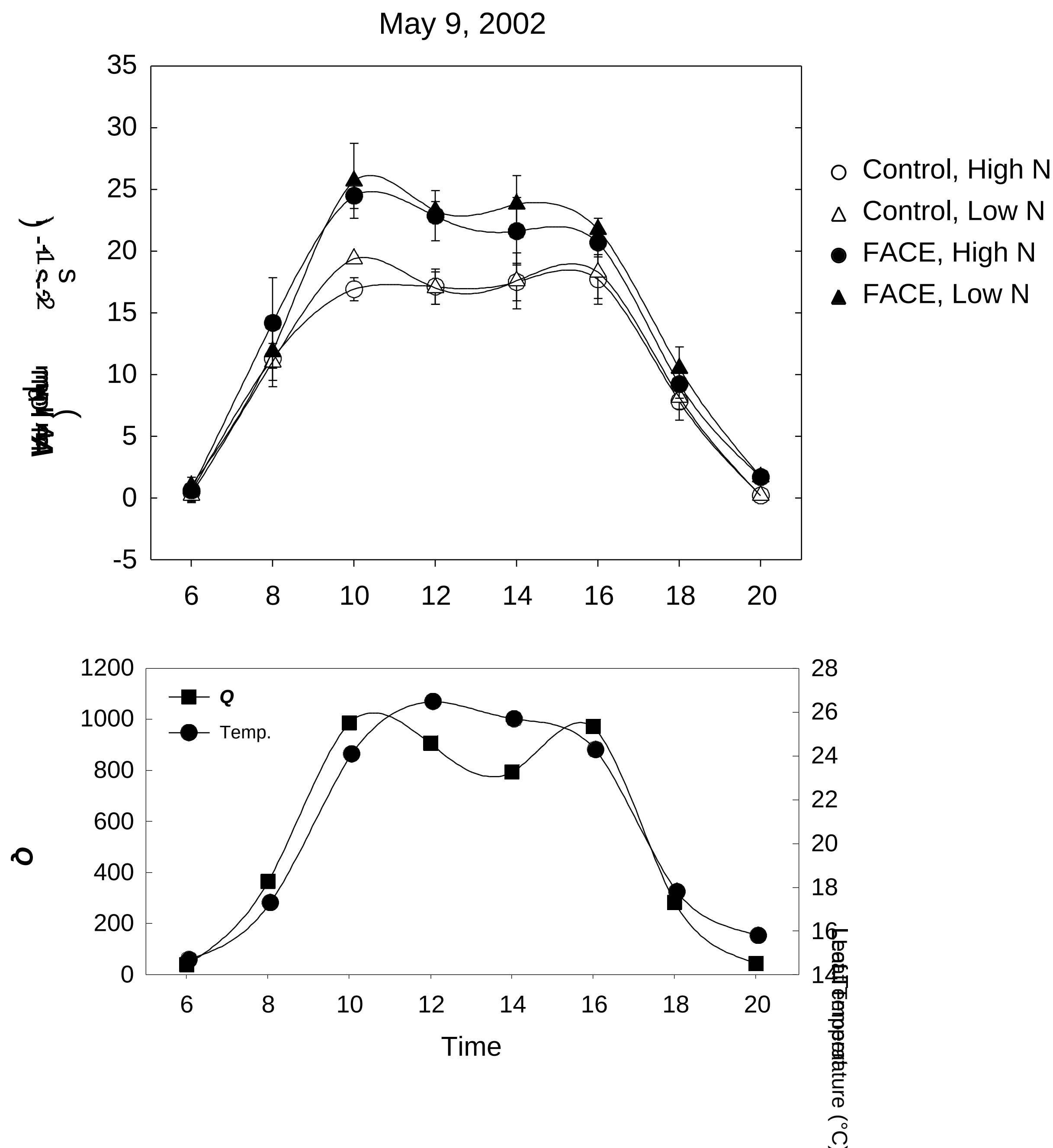


CLN: Control, Low N FLN: FACE, Low N CHN: Control, High N FHN: FACE, High N

Diurnal Carbohydrate Levels, April 28, 2001



CLN: Control, Low N FLN: FACE, Low N CHN: Control, High N FHN: FACE, High N


May 9, 2002
Control, High N
Control, Low N
FACE, High N
FACE, Low N
Q
Temp.
Time

Diurnal Photosynthesis and Carbohydrate Fluxes

Conclusions

- Elevated [CO_2] stimulated photosynthesis throughout the duration of the experiment.

- Acclimation of photosynthesis to elevated [CO_2] occurred in both High N and Low N fertilization treatments.

- Acclimation was more pronounced under Low N.

- Under Low N conditions, a high accumulation of carbohydrates in leaves was evident late in regrowth when percent stimulation of photosynthesis and $\boldsymbol{V}_{c,max}$ were significantly reduced.

- These results suggest that a severe carbon source-sink imbalance occurs late in regrowth; limitation of sink development has a negative feedback affect on photosynthesis.

Acknowledgements

Advisor: Steve Long

DOE Mentors: George Hendrey & Alistair Rogers

ETHZ: Urs Aeschlimann, Herbert Blum, Joseph Nösberger, Manuel Schneider, Daniel Suter

University of Essex: Jon Anderson, Jon Bryant, Rebecca Creasey, Phil Davey, Paul Humphries, Graham Hymus, Colin Osborne, Jon Williams

Funding: Graduate Research for the Environment, Global Change Education Program, DOE